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16. Abstract <p>This report is a first look at potential ways of providing solid-waste management for a building complex serviced by a modular integrated utility system (MIUS). Literature surveys were conducted to investigate both conventional and unusual systems to serve this purpose. The advantages and disadvantages of the systems most compatible with MIUS are discussed.</p>					
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GENERAL SURVEY OF SOLID-WASTE MANAGEMENT

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PREFACE

The Department of Housing and Urban Development (HUD) is conducting the Modular Integrated Utility System (MIUS) Program devoted to development and demonstration of the technical, economic, and institutional advantages of integrating the systems for providing all or several of the utility services for a community. The utility services include electric power, heating and cooling, potable water, liquid-waste treatment, and solid-waste management. The objective of the MIUS concept is to provide the desired utility services consistent with reduced use of critical natural resources, protection of the environment, and minimized cost. The program goal is to foster, by effective development and demonstration, early implementation of the integrated utility system concept by the organization, private or public, selected by a given community to provide its utilities.

Under HUD direction, several agencies are participating in the HUD-MIUS Program, including the Atomic Energy Commission, the Department of Defense, the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Bureau of Standards (NBS), the Department of Health, Education, and Welfare, and the Department of the Interior. The National Academy of Engineering is providing an independent assessment of the Program.

This publication is one of a series developed under the HUD-MIUS Program and is intended to further a particular aspect of the program goals.

COORDINATED TECHNICAL REVIEW

Drafts of technical documents are reviewed by the agencies participating in the HUD-MIUS Program. Comments are assembled by the NBS Team, HUD-MIUS Program, into a Coordinated Technical Review. The draft of this publication received such a review and all comments were resolved.

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GENERAL SURVEY OF SOLID-WASTE MANAGEMENT

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SUMMARY

Candidate solid-waste collection, transportation, and disposal systems are described in this report. The various types of solid-waste processing equipment available for use in a modular integrated utility system are presented. Automated collection systems are discussed, and the advantages and disadvantages of pneumatic collection systems are enumerated. Reclamation and recycling of solid wastes are discussed, and the processes used to separate solid waste into its various fractions are emphasized. The advantages and disadvantages of various types of incinerators are discussed. The final disposal process discussed is pyrolysis, which provides for the recovery of energy in the form of gas, oil, and char. The considerations for components to be used in a modular integrated utility system are discussed.

INTRODUCTION

The purpose of this report is to describe, qualitatively, the technology of modern solid-waste management systems. This technology description is written to relate solid-waste management systems to the modular integrated utility system (MIUS) concept. When comparing the various system concepts to determine the optimum system for an MIUS, consideration will be given to economics of operation, capital costs, efficiency, maintenance, reliability, and necessary development effort.

Although the use of existing technology in the form of garbage grinders, compactors, and pneumatic, vacuum, and gravity transport systems can reduce present costs, these systems should be considered for an MIUS on the basis of environmental and economic impact. Reclamation and recycling are advantageous because the use of these

processes conserves natural resources and disposes of solid wastes without polluting the environment; however, these operations are expensive, and there is almost no market for recovered components at this time. Incineration systems can be considered for an MIUS because they are capable of reducing solid wastes to a product or form of energy that can be used by another utility. The process of pyrolysis is also capable of reducing wastes to usable energy and, in addition, this energy can be stored for use at a later time.

In conducting this technology survey, several Government and private organizations were contacted and visited. The discussions with these agencies and firms provided relevant information concerning the solid-waste management systems in use today and the applicability of these systems to MIUS. A list of these contacts is given in table I.

As an aid to the reader, the original units of measure are in the Systeme International d'Unites (SI). The SI units are written first, and the English or conventional units are written parenthetically thereafter.

COLLECTION AND STORAGE

Manual techniques, rather than mechanical and automatic devices, are used for home and commercial refuse storage and for refuse collection systems. Solid-waste storage at or near the generation site is usually accomplished with reusable containers. In locations such as high-rise apartments, office buildings, and department stores where large quantities of refuse are generated and storage facilities are limited, compaction is often practiced. Onsite collection is done manually or, in high-rise installations, by gravity chutes. The use of slurry collection systems in apartment buildings has not been successful.

Pneumatic trash collection is now being introduced to the United States by several companies (the Envirogenics Co. (automatic vacuum collection system), Eastern Cyclone Industries, Inc. (Air-Flyte system), and Montgomery Industries, Inc. (Trans-Vac system)). These systems permit automatic, rapid transport of refuse from several locations near points of generation to a central storage location.

An overview of the techniques used for the collection and storage of refuse before ultimate disposal is presented in the following discussion.

Pneumatic Collection System

Automatic vacuum collection system.- An automatic vacuum collection (AVAC) system is currently in use at the Martin Luther King Hospital in Los Angeles, California, and a similar system is being installed at the Jersey City Breakthrough site.

The AVAC system is a horizontal system of pipes with an exhaustor at one end and air inlets at the end of each branch line. When the system is in operation, a vacuum develops at the inlet of the exhaustor, and a high-velocity airstream is drawn through the transport pipes from each air inlet. Throughout the system, vertical gravity chutes are provided with valved transition to the horizontal pipe system. Waste material is collected and stored at the base of each vertical chute and then dropped into the moving airstream. The airstream transports the material to a collection hopper where the material is deposited; then, the air moves through a filter and is discharged to the atmosphere. Air moves in the system at the rate of 24 m/sec (80 ft/sec). The operation of the system is not continuous. After each cycle, the collection hoppers are emptied automatically into equipment for ultimate disposal and processing. The system is actuated either manually by pushbutton control or on demand through limit switch controls at storage points. A flow diagram of the AVAC system is shown in figure 1. A schematic diagram of the system, as installed in hospitals for handling linens and trash, is shown in figure 2.

Air-Flyte system.- Negative air pressure is used in the Air-Flyte system to move bagged wastes through a tube or piping system from depository stations strategically located within buildings or a building complex to points of processing or disposal. An installation of this type is in use at the Alta Bates Hospital, Berkeley, California. A single tube, usually between 30 and 51 centimeters (12 and 20 inches) in diameter is used in the most common system. Automatic switching devices are used in hospital installations to direct linens or trash to the proper destination. Single-tube systems are equipped with either one- or two-door depository stations (although both in the latter case are connected to the same single tube). Systems

in which separate tubes are provided for linen and trash can be installed. The operations of single- or two-door systems and single- or dual-tube systems are controlled by a pushbutton at the loading station. The system is designed to dispatch one bag from one loading station to a selected destination at any given time. The memory system, similar to the type used for elevator control, records demands from several stations and activates the inner doors of the various receivers throughout the system in a time sequence corresponding to the order in which the demands were placed.

Trans-Vac system.- A Trans-Vac system prototype is operating at Montgomery Industries, Inc., Jacksonville, Florida, with the capability of moving bagged or loose wastes within or between buildings to a central collection station for processing and/or storage. The Trans-Vac systems use vacuum, a combination of gravity and pneumatic control, or positive pressure methods.

Advantages and disadvantages of pneumatic collection systems.- Pneumatic waste-collection systems offer the following advantages.

1. Odor and spillage are minimized.
2. Noise from refuse collection trucks is eliminated.
3. Handling by sanitation personnel is reduced.
4. Increased loads can be handled without increasing collection rates.
5. Operating cost is low compared to present collection systems. Automated operation requires fewer personnel.
6. Low maintenance is required.

The main disadvantage of the pneumatic waste-collection system is the high initial cost of installation. However, economic evaluations conducted by pneumatic collection system manufacturers indicate that these systems are cost competitive because labor and maintenance costs are minimized and the systems have a longer operational life than conventional collection systems. Another important disadvantage is the systems inability to collect bulk refuse such as appliances and other large items.

Compaction

In locations such as high-rise apartments, office buildings, and department stores where large quantities of refuse are generated and storage facilities are limited,

compaction is often practiced. Compactors normally reduce the volume of refuse by 2 to 1 although there is equipment available with the capacity for a compaction ratio as high as 8 to 1. Compaction of refuse is sometimes required in densely populated areas where space is limited. Compaction of refuse also reduces rodent and insect problems in storage areas.

Methods of Collection Used in Cities

New equipment being used in some small cities includes waste-collection trucks with mechanical arms for lifting containers or bags. The common method of individuals carrying containers from curb to truck is quite costly in terms of labor and time to fill one truck. The average cost of conventional collection is approximately \$20/Mg (\$18/ton) of refuse.

Residential garbage is often introduced into sewage systems through sink garbage grinders, which are a popular appliance being installed in new housing. However, there are differing viewpoints among city officials concerning the collection and disposal of ground garbage in municipal waste-water-treatment plants. Some cities welcome the use of home disposal units because quantities of putrescibles in curbside storage containers are reduced, whereas the use of these units is discouraged in other cities because some waste-water-treatment systems cannot tolerate the additional load. Collection methods used in high-density areas vary with the municipality. In many cases, the city Government will not collect or dispose of refuse from apartments and commercial establishments. In these situations, private collection and disposal companies are relied on. Refuse from these establishments is usually stored in large containers, sometimes compacted, and collected by compactor trucks that are specially designed to interface mechanically with the containers to facilitate loading.

RECLAMATION AND RECYCLING

Reclamation and recycling of solid-waste materials conserve natural resources and dispose of solid waste without polluting the environment. The first step in reclamation and recycling is the separation of various materials from the solid-waste stream. One method of separation is to divide the wastes at the point of

generation according to combustible and noncombustible material. (This separation could be accomplished with a pneumatic waste-collection system that has two chutes.) By partial separation at the source, the cost of ultimate reclamation and recycling is reduced. In reclamation and recycling plants, ferrous metals are separated by magnetic separators. These systems are being used by some large incinerator installations for salvaging tin cans. Sorting materials of various types by hand is used in some operations; but this is quite expensive, and the amount of material salvaged is small. Separating materials by air classification has been tested, but size reduction is required before air classification can be performed.

The major problem with recycling solid-waste materials is one of economics. There is some market for paper and tin cans, but other materials are seldom in demand. For example, a plant separating paper, glass, and ferrous metals has operating costs averaging approximately \$5.50/Mg (\$5/ton) of refuse, which only saves approximately \$3.30/Mg (\$3/ton) more than the incineration process. This example assumes that there is a market for the recovered components in the immediate area. Unfortunately, the buyers of salvaged metals, glass, and paper are few, and transportation costs are high. In addition, the paper and glass industries are not presently equipped to process recycled materials, because cheap and abundant supplies of raw materials and internally generated scrap are available.

Air Classification

Air classification is an operation in which a mass of granular particles of mixed sizes and different specific gravities is allowed or caused to settle through a fluid that may be either in motion or substantially at rest. Another process used in conjunction with air classification is sizing, or screening, which is the separation of various particle sizes into two or more portions by a screening surface that acts as a multiple "go" or "no go" gage so that the final portions consist of particles of more nearly uniform size than those of the original mixture. Research is being performed in air classification at the Stanford Research Institute and at the Bureau of Mines at College Park, Maryland. A device used at the Metropolitan Waste Conversion Plant of Houston, Texas, to remove glass and nonmetallics from compost is called a stoner. This device, which separates material primarily on the basis of differences in specific gravity, is manufactured by Sutton,

Steele, and Steele of Dallas, Texas. A stoner is a dry vibrating table that operates by passing a stream of air upward through an inclined screen or perforated table. The material to be sorted enters near the top of the inclined screen. Lighter particles are buoyed up by the air passing through the screen and flow downward to the lower end where they are discharged. The inclined screen vibrates in an oscillating motion that causes the dense particles to migrate upward along the screen surface and discharge over the higher end of the table.

Optical Sorters

Optical sorters can be used to separate various colors of glass. Buyers of glass cullet require complete separation of glass with respect to color and magnetic properties. An optical sorter that will achieve this degree of separation is being developed by the Bureau of Mines using a machine built by the Sortex Company of North America.

Composting

Compost is a humuslike material that results from the biochemical degradation of the organic fraction of solid waste. This process is generally used in conjunction with a recycling operation. A schematic diagram of the process used by the Metropolitan Waste Conversion Corporation of Houston, Texas, is shown in figure 3. A mechanical digester is used in this process to speed up the composting process. Windrow composting requires large areas for processing and approximately 6 weeks for completion, which includes 2 weeks for curing and drying. The curing or maturing time for the Fairfield-Hardy process digester, used by the Fairfield Engineering Company, is from 1 to 3 weeks. Sewage sludge is added in many cases to provide additional nutrients.

The advantages and disadvantages of composting are as follows:

<u>Advantages</u>	<u>Disadvantages</u>
1. Conservation of natural resources	1. Requirement for substantial manpower
2. Reduction in amount of landfill areas	2. Insufficient market for reclaimed materials

- | | |
|-----------------------------|-------------------------|
| required | 3. Limited and seasonal |
| 3. Reduction or elimination | market for compost |
| of incinerator | 4. Large amount of land |
| requirements | required for windrow |
| 4. Adequate handling of | composting |
| sewage sludge | |

INCINERATORS

Volume can be reduced by solid-waste incineration, but ultimate disposal still requires landfill. A simple incinerator burns refuse by increasing the charge temperature to the point of combustion in the presence of air. Assuming that sufficient oxygen is available, efficient incineration will reduce municipal solid waste to inert residue that is approximately 5 percent of the original volume.

Volume reduction can be achieved with current incinerator technology, but considerable monetary and environmental expense is involved. Incineration of 900 kilograms (1 ton) of refuse costs approximately \$8 compared to \$20/Mg (\$3/ton) for sanitary landfill based on a 900 000 kg/day (1000 ton/day) operation. Although municipal refuse is generally able to sustain combustion after ignition, considerable auxiliary fuel must be expended and/or excess air must be introduced for maximum volume reduction. If combustion chamber temperatures rise above 1400 K (2000° F), harmful nitrogen oxides are formed and released into the atmosphere. Incomplete combustion releases carbon monoxide and hydrogen chloride. High burning rate, high ash content of refuse, combustion chamber turbulence, and excess air can cause undesirable particulate emissions. The design of incinerators that achieve a high volume reduction with minimum economic and environmental impact is being actively pursued. The Environmental Protection Agency (EPA) is funding university projects for developing laboratory-scale systems and municipal demonstration units of innovative incinerator and recovery system design. In addition, private industry is pursuing unique processing methods in the laboratory and in pilot plant operations.

Conventional Incinerator

Most present-day municipal incinerators are modified and improved versions of basic designs that have been in existence for 20 years. A diagram of a typical municipal furnace is shown in figure 4. The single chamber, horizontal grate incinerator has been improved by mechanical stacking, the addition of a secondary combustion chamber or afterburner, automatic feeding devices, and temperature controls. The traveling grate furnace, in which the refuse is introduced into a rectangular combustion chamber at the top of a movable, inclined grate and then tumbles to a residue collection pit, has been improved by adding an afterburner and redesigning the grate to increase the agitation of the refuse charge and to increase the quantity of underfire air introduced. The rotary-kiln type incinerator in which refuse is introduced at the top of an inclined, rotating, cylindrical combustion chamber is also in use.

With respect to more sophisticated designs now in development, the advantages of these conventional incinerators are noteworthy. The basic conventional incinerator generally does not require charge preparation, needs only minimal time for startup, and is relatively inexpensive. Reliability and the knowledge of deficiencies from operational experience are the major advantages of these incinerators.

The disadvantages of conventional incinerators include low burning rates and rapid deterioration of equipment as a result of corrosion and erosion. Older furnaces with fewer automatic controls are expensive to operate because labor costs, even on modern incinerators, approach 50 percent of annual operating expenditures. The most significant problem with conventional incinerators is air-pollution control. Efficient, complete combustion is difficult to maintain. Less than complete combustion will result in air-pollution problems as noxious gases, odors, and particulate matter are released to the atmosphere. In attempting to solve the air-pollution problem, two possibilities have been investigated. The most expedient solution has been the addition of control devices that remove suspended particles; however, a reassessment of combustion chamber configurations, of the use of auxiliary fuel, and of the addition of excess air and turbulence in the chamber has been made.

Air-pollution control devices remove only particulate matter by mechanical methods or by precipitation. Both

methods decrease the efficiency of the incinerator system because they result in pressure drop across the gas stream exit. Mechanical methods include settling chambers, in which removal depends on gravity, and cyclones that operate by centrifugal force. Wetted baffle systems in which particles are entrapped on water film have been in use since the 1950's. Another method, although not in extensive use, is a bag or fabric filter. Filters are very efficient but temperature problems, frequent cleaning, and high pressure drops have limited their use. The efficiency of mechanical controls rarely exceeds 50 percent because they are incapable of removing significant quantities of small particles. With the exception of bag filters, individual use of any of these methods would not meet the Federal Air Pollution Control Standards for modern incinerators.

Particulate removal by precipitation is more efficient and more widely used. Wet scrubbers of various designs are the most prevalent means of removal by precipitation. Scrubbers remove suspended particles by collecting them on droplets of water introduced into the exhaust gas stream. Although the efficiency of this type system can approach 99 percent, it is directly proportional to the amount of energy expended in producing the spray. As the spray becomes finer, efficiency as well as expense are increased. There are two major disadvantages of scrubber systems. The first is corrosion associated with the dissolution of carbon dioxide and hydrogen chloride in the water. The second and most significant problem is the disposal of the contaminated effluent water. Stringent water-quality regulations being adopted nationwide will prohibit the release of this water without treatment to neutralize the high acid content.

Electrostatic precipitators are even more efficient than scrubbers but their use on municipal incinerators in the United States has been limited because of the high capital cost. As effluent treatment requirements become more strict, the cost of the electrostatic precipitators will probably become more competitive. In the operation of an electrostatic precipitator, particulate matter is electrically charged and then collected as it passes through an electric field. As with scrubbers, the efficiency is proportional to the energy or power input to the system. The use of scrubbers and precipitators is also limited by the temperature of the effluent gases. As a result of excessive stack temperatures, above 533 K (500° F), great quantities of scrubber water will evaporate, and the efficiency of electrostatic precipitators will be reduced.

The single chamber, horizontal grate incinerator has evolved to a multiple chamber unit. The refuse is fed to the primary chamber where distillation occurs. The effluent gases are directed into a secondary chamber where they are consumed. This use of multiple chambers and auxiliary fuel reduces particulates to acceptable levels, and no other air-pollution controls are necessary in most instances. Emission problems with the traveling grate-type furnace have also been lessened by the addition of an afterburner section. An example of a multiple chamber incinerator marketed by the Waste Combustion Corporation is shown in figure 5.

The conventional incinerators described in this section have been successful in meeting the needs of municipalities throughout the United States. However, as the availability of sanitary landfill sites diminishes, as raw materials supplies for industry decrease, and as the supply of fossil fuels is expended, this approach to solid-waste disposal will change. More volume reduction will be performed to allow extraction of materials for recycling, and the energy value of refuse will be used. Research and development work is proceeding, and important improvements have already been demonstrated in incinerator design. Innovative types of incinerators now being demonstrated are the suspension burner, the high-temperature furnace, and the fluidized-bed incinerator.

Suspension-Burning Incinerator

Suspension-burning incinerators use cylindrical combustion chambers in which high-velocity air is introduced tangentially to cause high turbulence and to facilitate burning. The primary advantages of this type incinerator are improved combustion, high refuse consumption rate, and small size. The use of this incinerator for municipal wastes requires preparation of the refuse by a shredder before combustion, and large quantities of excess air must be used to create the turbulence. A "Vorcinerator" developed by the General Electric Company is being used in a demonstration project at Shelbyville, Indiana. Another design, presently being installed in a Houston hospital, is manufactured by Ecology Industries, Inc.

High-Temperature Incinerator

Conventional incinerators operate in the temperature range of 1000 to 1300 K (1600° to 1800° F). Higher temperatures result in slagging of glass and molten metals, which causes clinkers, damage to grates, and slag buildup on the refractory surfaces. Furnaces can be designed to operate at temperatures of 1400 to 1900 K (2000° to 3000° F), however, and they offer the advantage of additional volume reduction and produce a residue that may be useful as aggregate for building blocks and highway construction. Concepts related to the steel and coke industry are being incorporated into the current development of several municipal waste incinerators. These units are being developed by private industry and, to date, no large-scale demonstration projects are in continuous operation. Because oxides of nitrogen form at high temperatures if excess oxygen is available, precautions must be taken in designing these incinerators.

Fluidized-Bed Incinerator

The EPA is also funding a development project, CPU-400, that is being built by the Combustion Power Company. This project is a complete solid-waste handling facility including shredder, separator, air classifiers, incinerator, particulate removal equipment, and waste energy equipment. Each component of the system is being optimized before integration into the system. The incinerator that is being developed is a fluidized-bed type previously used in the incineration of liquid and carefully prepared solid industrial waste.

A fluidized-bed incinerator consists of a cylindrical chamber, partly filled with granular solid (sand), that is resting on a porous plate. Air is introduced through the porous plate at the proper flow rate, which causes the sandbed to expand, thereby increasing the free area for gas flow to the point where the bed acts as a fluid (i.e., the bed has apparent viscosity and will flow). This particular model will operate at an air pressure of $4.14 \times 10^5 \text{ N/m}^2$ (60 psi). The bed also has a very high heat-transfer rate due to the particle turbulence. In this use, the sand is heated to approximately 1100 K (1500° F), and the prepared solid waste is injected into the bed where it is rapidly consumed. Strict temperature limitations must be maintained during operation so that slagging of the sand and residue does not occur. When the entire CPU-400 system is

integrated and operational, the exhaust gases from the incinerator will be cleansed by inertial separators and then used to drive a gas turbine coupled to an electrical generator. Because the complete system is not yet operational, no cost estimates are available.

PYROLYSIS

Pyrolysis can be defined as chemical decomposition by heat. As applied to municipal refuse, pyrolysis is the destructive distillation of the organic fraction in the absence of oxygen by heating. The high temperatures used (400 to 700 K (500° to 900° C)) and the lack of oxygen result in a chemical breakdown of the organic materials into three component streams: (1) gas, including hydrogen, methane, carbon monoxide, carbon dioxide, and a small percentage of more complex hydrocarbons; (2) liquid, consisting mainly of water with small amounts of acids, ketones, aldehydes, light oils, and tar; and (3) solid, identified as char. The percentages of the product fractions vary because of the heterogeneous nature of the refuse, the temperature attained, and the heating rate of the pyrolyzing chamber.

Pyrolysis of municipal refuse is an attractive method of disposal for several reasons: (1) Because the rate of gas evolution is low, entrapped particles are kept to a minimum, and air-pollution controls are unnecessary. Condensing equipment on the effluent line removes hazardous liquid and gas products. (2) More than 90 percent of the energy value of the raw refuse can be recovered as useful products. (3) The process is self-sustaining through the use of gaseous products as a heat source.

With respect to a continuously operating municipal plant, the advantages and disadvantages of the process are not well defined because the process is still in the experimental stage of development. Considerable preparation of the refuse is apparently required if useful products are to be obtained. Separation, removal, and shredding of the organic fraction are required; some drying of the refuse is desirable.

Laboratory-scale studies funded by the EPA have been performed by R. Pailie at the University of West Virginia, by a group at the University of California at Berkeley, and by E. R. Kaiser at New York University. Monsanto, Cities

Service, Garrett Research Center, and Battelle, among others, have conducted research in adapting the process to solid-waste disposal. The Pittsburgh Energy Research Center of the Bureau of Mines performed some investigative testing with a batch retort unit that pyrolyzed approximately 23 kilograms (50 pounds) of sorted and shredded refuse, condensed the liquids, and routed the product gases through a series of acid and caustic scrubbers to improve their value.

Testing beyond laboratory-scale studies has been minimal. The Bureau of Mines is interested in building a 900 kg/day (1 ton/day) unit with continuous feed; however, to date, funding has not been appropriated. A schematic diagram of this unit is shown in figure 6. The University of California at Berkeley built a 7 kg/hr (16 lb/hr) unit with continuous feed and made favorable comparisons with their laboratory tests. Because the EPA is no longer funding this research, the future of this unit is uncertain. Garrett Research and Development, Inc. is presently operating a 3600-kg/day (4 ton/day) pilot plant in La Verne, California. The city of San Diego has been awarded an EPA grant to build and operate a disposal plant in which the Garrett process is used. This plant should be in operation by 1975. The Garrett pyrolysis process needs development at the pilot plant level. The present disadvantages are extensive preprocessing of the refuse material and the requirement for shredding, drying, removal of the inorganic component, and then grinding. There are several parts of the process that would benefit from additional research. It appears that the basic distilling unit can be optimized by using multiple-stage reactors. A low-temperature first stage or dryer can be incorporated to remove moisture from the refuse and thereby improve the value of the effluent gases.

Fluidized-bed reactors in which the organic refuse forms the bed held in suspension by recycled gaseous products may be used. Rotary kiln reactors can be used to improve heat transfer to the refuse. With respect to heating rates and final temperature, fine tuning of the distillation stage would improve the value of the product gases. The use of catalysts to inhibit char formation and reform gases should also be investigated. The Bureau of Mines unit incorporates acetic and caustic scrubbers to cleanse the effluents. They also recommend use of the char product as a filter for the liquor product, which is primarily water. The condenser and product treatment areas need further improvement.

CONSIDERATIONS FOR MODULAR INTEGRATED UTILITY SYSTEMS

Collection Systems

The use of existing technology in the form of garbage grinders, compactors, and pneumatic, vacuum, and gravity transport systems will be evaluated for an MIUS. The elimination or reduction of odor, spillage, noise, and handling together with the automatic delivery of the waste to central storage areas are advantages of these devices. Use of these systems should be stressed in the MIUS project but considered on the basis of environmental and economic impact.

Processing Systems

Although sanitary landfill is the most environmentally acceptable method of ultimate solid-waste disposal, incineration systems are desirable for an MIUS because solid wastes can be reduced to a product or form of energy that can be used by other utilities.

The adaptation of a pyrolysis unit for MIUS should be explored. The fundamental advantage of a pyrolysis unit compared to an incinerator with heat recovery is the ability to store the energy derived from the refuse so that it can be used at the time when it is most needed by other utility subsystems. Pyrolysis systems now being developed expend this energy immediately in an afterburner or heat exchanger. Storage of the gas or liquid products for later use in operating a heat-recovery unit should be considered. A relatively large percentage of the product gas is hydrogen. Segregation of this hydrogen for use in fuel cells is also an intriguing idea. Disposal of raw sewage or sewage sludge effluent by pyrolysis concurrent with solid waste should be investigated. Pyrolysis of solid waste indicates definite potential although a significant amount of development appears to be necessary both in the laboratory and at the pilot plant level. Because the technology is available, this development effort should not be particularly time consuming or costly. If the economics of size are favorable, then adaptation of pyrolysis for the MIUS should be pursued because it offers distinct advantages for integration with the other utility subsystems. Integration of solid-waste processing with utility functions through sharing of components is another alternative.

To determine the optimum system for an MIUS, the economics of operation, capital costs, efficiency, maintenance, reliability, and necessary development effort will be considered when comparing the various alternative system concepts.

Solid-Waste Processing Costs

At a generation rate of 2 kg/day (5 lb/day) for each person, the solid-waste load in an MIUS demonstration project will be approximately 9000 kg/day (10 tons/day). Generalized capital cost estimates in the reviewed literature do not tabulate cost data on incinerator systems with a capacity less than 135 000 g/day (150 tons/day). An MIUS solid-waste processor that includes an automatically fed incinerator, possibly with the capability to incinerate sewage sludge, and a heat-recovery unit such as a waste-heat boiler could be designed and fabricated with available components. However, very few integrated systems of this type exist and none are of standardized design. The industry has chosen to design each system individually and tailor it to a specific use. As an estimate, an MIUS incinerator that could handle 9000 kg/day (10 tons/day) of solid waste and that would be capable of recovering heat would cost approximately \$140 000.

Capital costs for more advanced systems incorporating multiple chambers, high temperatures, suspension burning, fluidized beds, and various degrees of pyrolysis are difficult to estimate. These innovative systems usually offer some form of heat recovery integral to the unit and are attractive alternatives to a conventional incinerator that must be adapted for heat recovery. This advantage alone would not justify the selection of a novel system unless it was also cost competitive.

In some instances the removal of some percentage of the noncombustibles in the solid waste before incineration may be advantageous. The intention would be to raise the heating value of the refuse rather than to salvage the noncombustibles. Separation to any level would have to be evaluated with respect to process requirements and equipment costs. Although a large percentage of system operating costs is attributable to labor, an MIUS installation would be unique because operating personnel would be shared by other utilities.

Onsite solid-waste processing in the MIUS can offer significant cost advantages. Municipal collection, hauling, and disposal of the solid waste generated at the demonstration project could cost approximately \$24/900 kg (\$24/ton) or more, depending on the location. A rough estimate of amortized capital and operating costs of an onsite MIUS processing station with a collection system would certainly not exceed the \$24/900 kg (\$24/ton) estimate. This MIUS estimate does not include credit for recovered waste heat. Incineration of the sewage sludge would decrease the complexity and cost of the MIUS waste-treatment facility. An additional benefit would be the reduction of the local municipal collection and disposal requirements.

Onsite processing is not widely practiced for several reasons. The capital investment necessary for the processing equipment, the need for skilled operators, and the trend toward stricter air- and water-pollution regulations that make equipment obsolete before depreciation all contribute to the reluctance of builders to provide more than minimal refuse handling equipment. The MIUS processing scheme will have to address these problems.

CONCLUDING REMARKS

The solid-waste management subsystem to be used in a modular integrated utility system should be capable of producing products that can be used by other utilities. These products may take the form of steam or hot water, gas, oil, or other energy forms. Incinerators with heat-recovery equipment are currently being used. In the near future, pyrolysis plants that produce gas or oil may be available. The solid-waste management subsystem should also be capable of disposing of the sludge from the waste-water-treatment subsystem. To determine the optimum system for a modular integrated utility system, the economics of operation, capital costs, efficiencies, maintenance, and reliability will be traded off for the various types of available techniques.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, February 15, 1974
386-01-00-00-72

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C-E Combustopak Waste Disposal System. Combustion
Engineering, Inc., Windsor, Conn.

Consumat - Complete Incineration Systems. Waste Combustion
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Pollution Control Systems from Besser-Wasteco. Wasteco,
Inc., Tualatin, Oreg.

Incinerator Waste Disposal System, General Electric Co.,
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TABLE I.- COMPANIES OR AGENCIES CONTACTED DURING THE SOLID-WASTE MANAGEMENT SURVEY

Company or agency	Representative contacted	Mode of contact
Environmental Protection Agency	Clarence Clemons	Meeting at JSC (Cincinnati Solid Waste Office)
	Dick Chapman	Meeting at Palo Alto, Calif. (CPD-400)
	Ed Higgins, Darwin Wright, Dr. Skinner	Telephone conversation
Aerojet General Corp.	George Stevenson	Telephone conversation
Syska & Hennessey	Robert Manfredi, William Herdman	Meeting in Washington, D.C.
Bureau of Mines	C. B. Kenenhan, M. H. Stanczyk	Meeting in Washington, D.C.
University of Houston	H. Nugent Myrick	Meeting at JSC and at the University of Houston
Natural Center for Resource Recovery	M. J. Zusman	Meeting in Washington, D.C.
NASA Headquarters Technology Utilization Office	Tom Wakefield	Meeting in Washington, D.C.
Torrax Systems	J. Z. Stoia	Telephone conversation
Wasteco	Dean Robbins, Charles Hoar	Meeting at JSC
NASA Ames Research Center	Jacob Shipira	Meeting at Ames Research Center
Pennsylvania State Dept. of Health	Wayne Lynn, G. Echanon	Telephone conversation
Monsanto	Ed Stewart	Telephone conversation
Union Carbide	R. F. Paul	Telephone conversation
Ecology Industries, Inc.	Clem Mahon	Telephone conversation
M. D. Anderson Hospital	Bob Greaser	Meeting at M. D. Anderson Hospital
General Electric Co.	Donald R. Glenn	Meeting at JSC
City of Houston	Mr. Kroger	Telephone conversation
Boeing Vertol	L. Douglas	Telephone conversation
Brule' Incinerators	Bob Rowan	Telephone conversation
Metropolitan Waste Conversion Corp.	Victor Brown	Meeting in Houston
Barton Disposal Service	Mr. Barton	Telephone conversation
B & M Systems (Waste Combustion Corp.)	Gene Clark	Meeting in Houston
Bureau of Mines	D. P. Wolfson	Telephone conversation

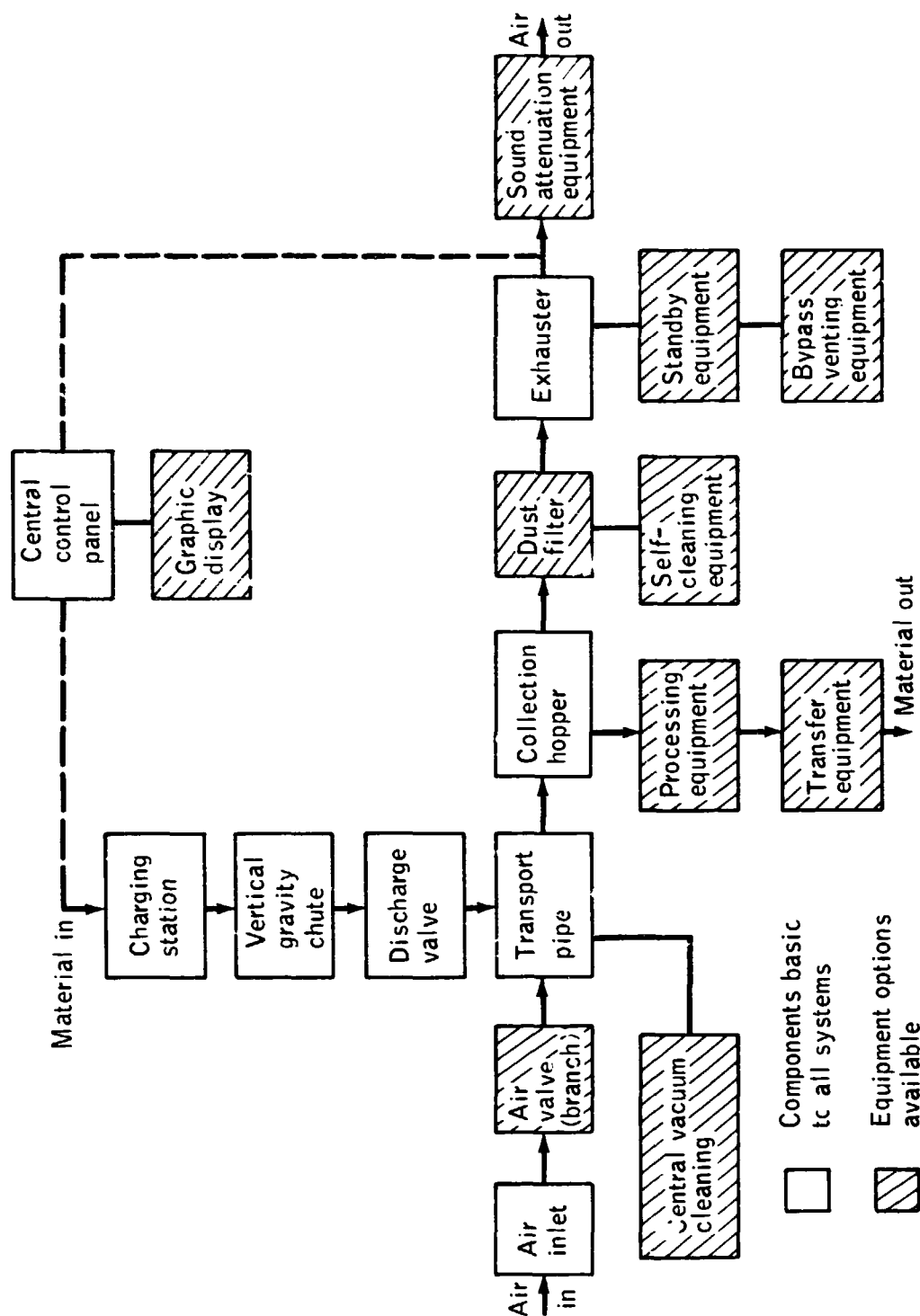


Figure 1.- Flow diagram of an automatic vacuum collection system.

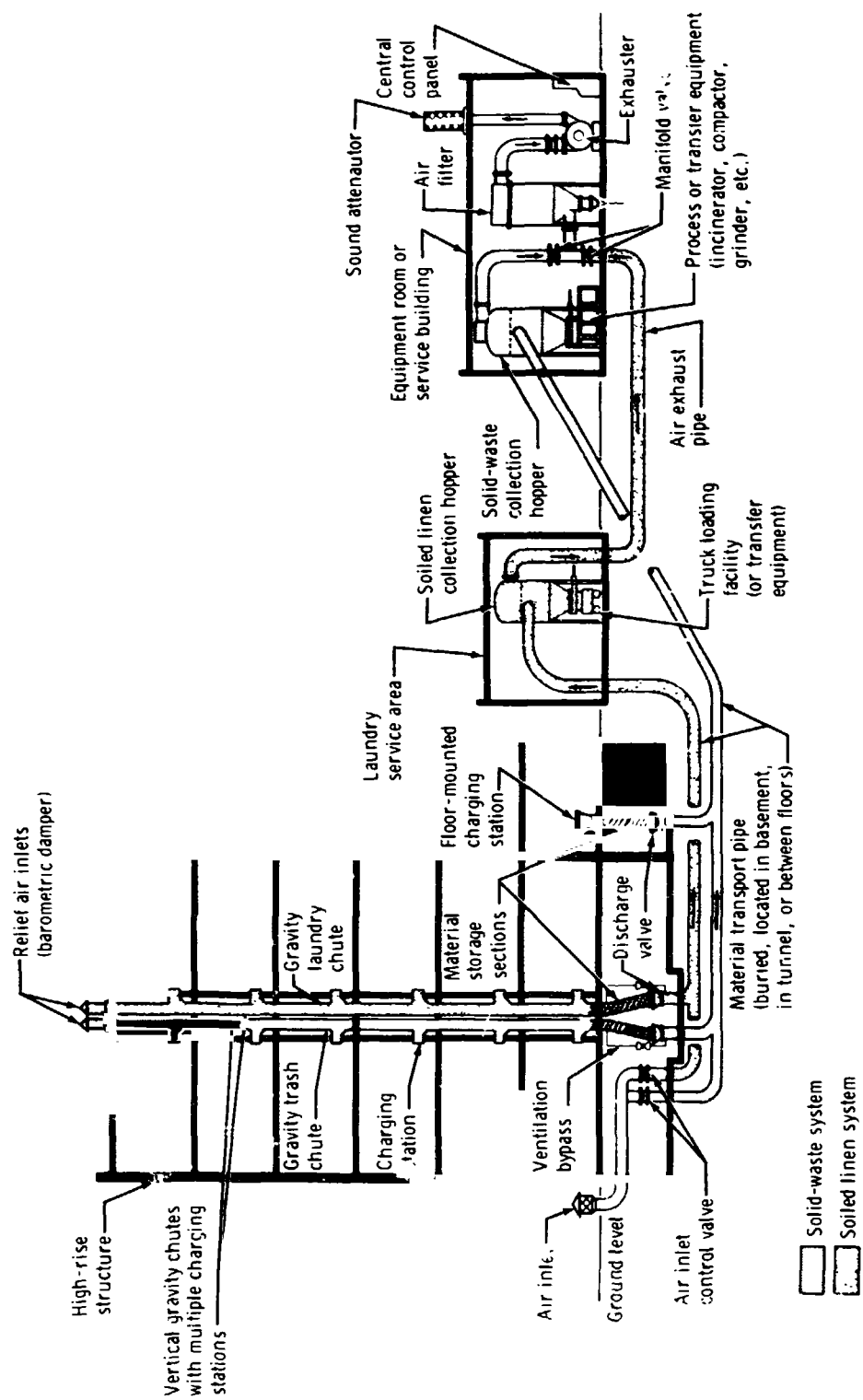


Figure 2.- Schematic diagram of an automatic vacuum collection system.

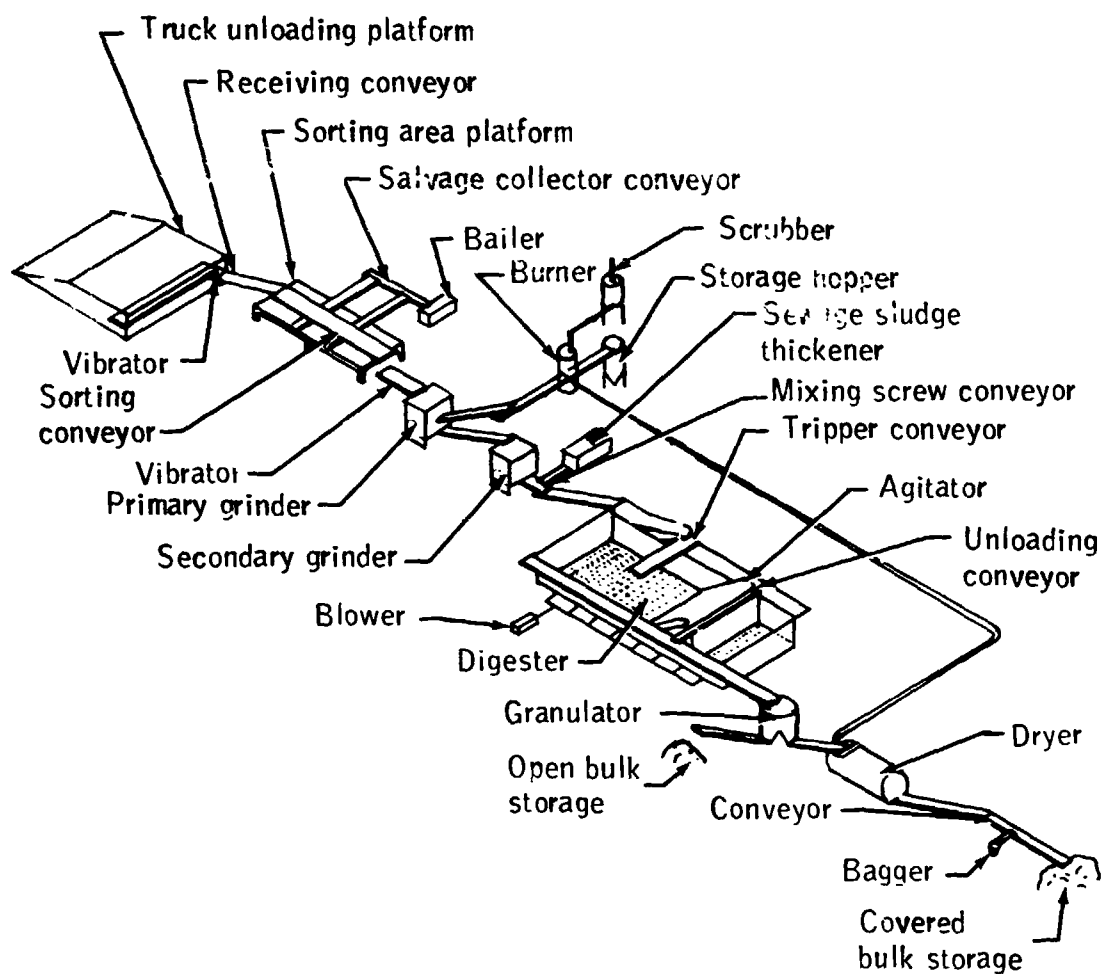


Figure 3.- Schematic diagram of the Metropolitan Waste Conversion Corporation plant.

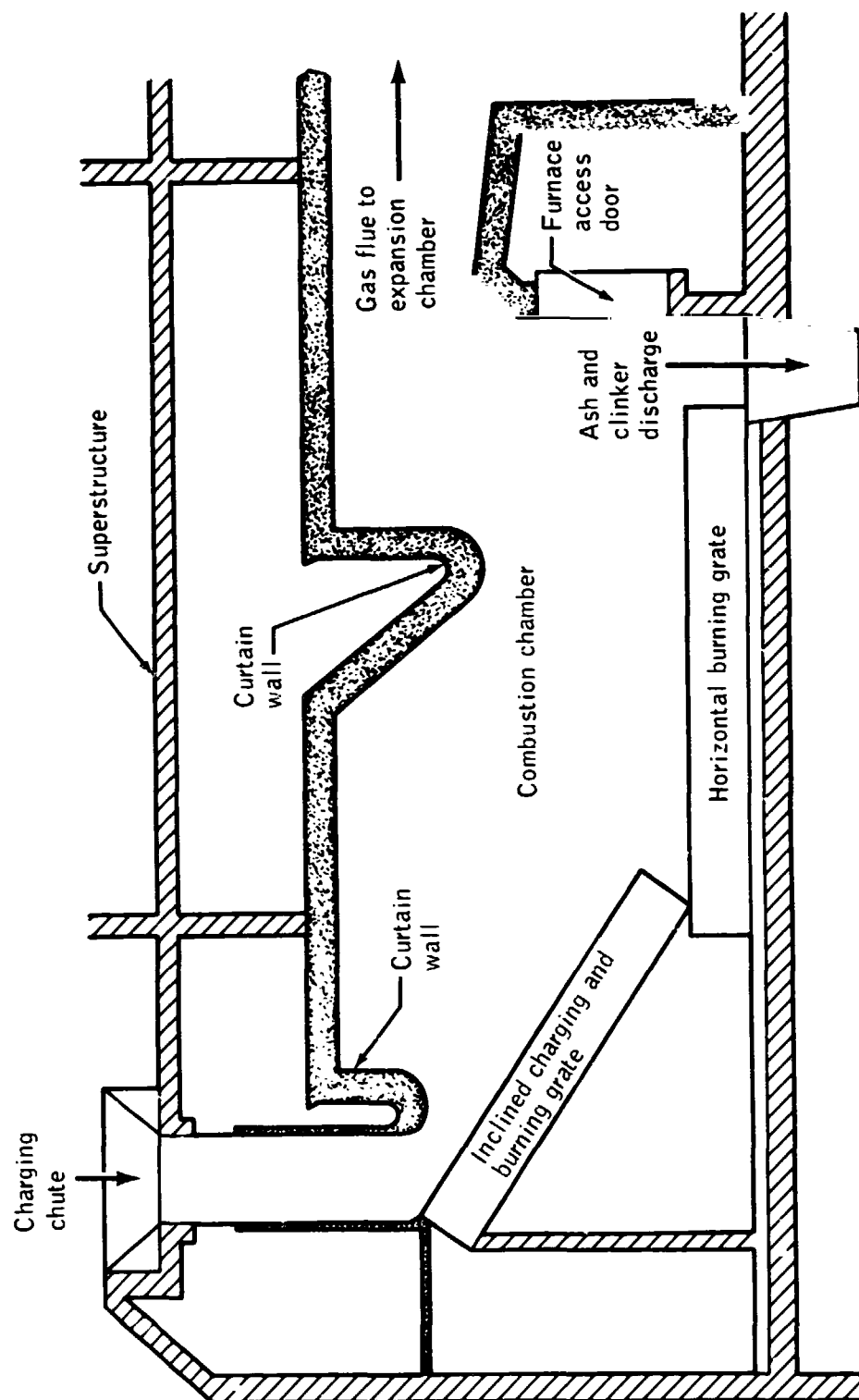


Figure 4.- Flow diagram of municipal incinerator.

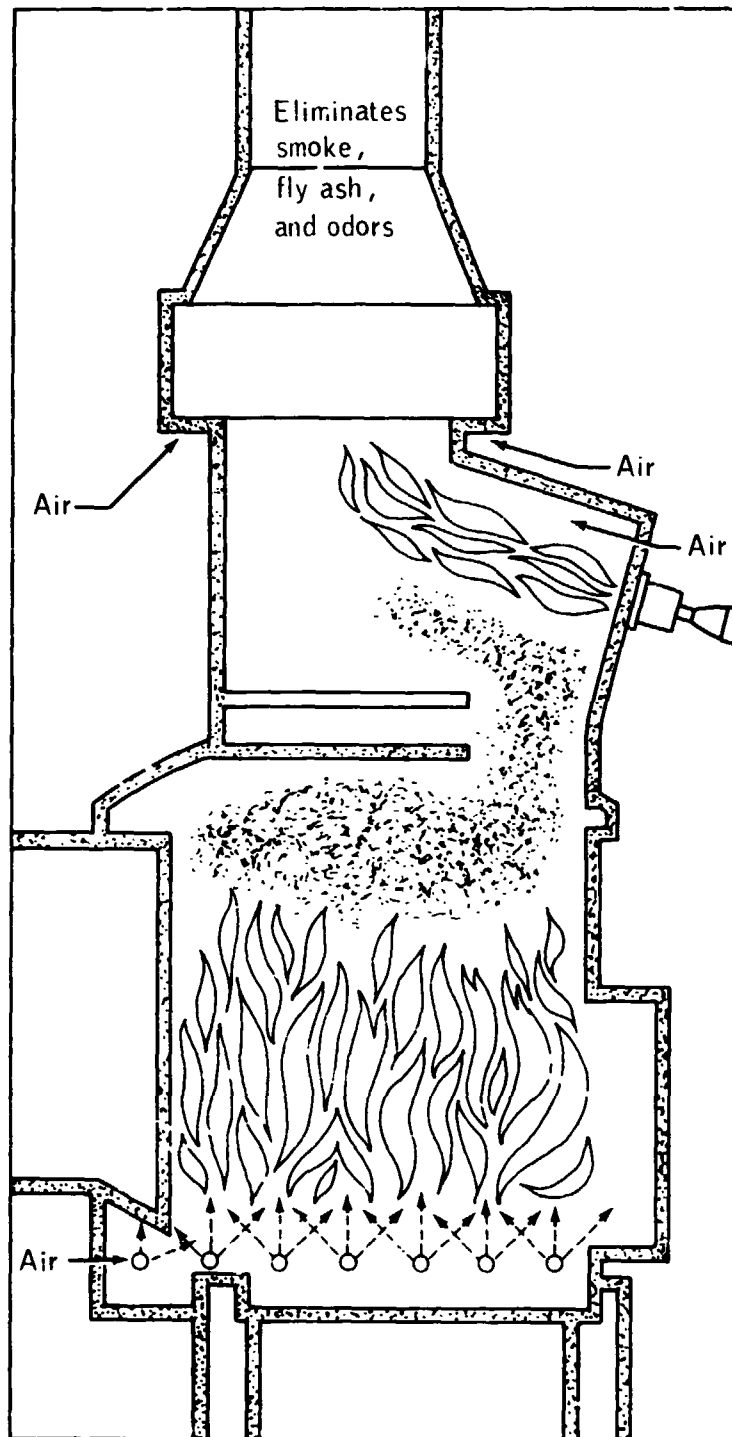


Figure 5.- Flow diagram of Waste Combustion Corporation incinerator.

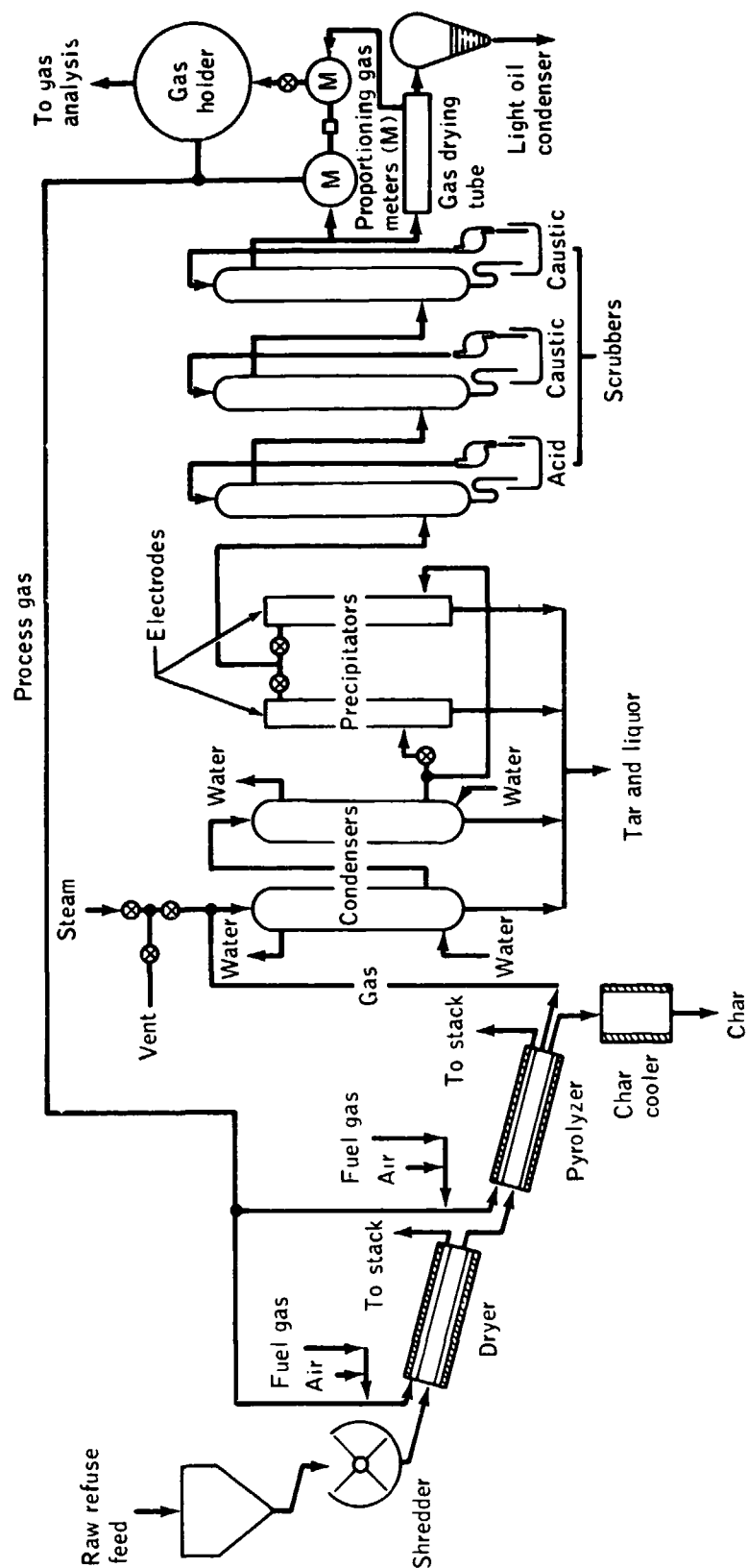


Figure 6.- Schematic diagram of Bureau of Mines pyrolysis unit.